D 742661

RM-542

MICROSTRUCTURAL OBSERVATIONS

OF FUSION WELDED

BORON-ALUMINUM COMPOSITES

May 1972

RESEARCH DEPARTMENT

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
Grumman Aerospace Corporation	Unclassified
	2b. GROUP n/a

3. REPORT TITLE

Microstructural Observations of Fusion Welded Boron-Aluminum Composites

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Research Memorandum

5. AUTHOR(S) *(First name, middle initial, last name)*

James R. Kennedy

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
May 1972	12	11

8a. CONTRACT OR GRANT NO. none	9a. ORIGINATOR'S REPORT NUMBER(S) RM-542
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* none
d.	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited

11. SUPPLEMENTARY NOTES None	12. SPONSORING MILITARY ACTIVITY n/a

13. ABSTRACT

Welding studies were conducted on boron-aluminum (B/Al) composites to observe the effects of gas-tungsten arc fusion welding on the boron reinforcing filaments and aluminum matrix. The objective of this investigation was to determine the basic potential of fusion welding B/Al composites for possible structural applications. Microstructural observations after welding revealed matrix fusion without apparent boron filament damage. Analysis of weld metal regions indicated that aluminum filler metal additions intermixed with the matrix and altered its chemical composition. It is concluded that fusion welding of B/Al composites may be possible by control of welding energy input.

DD FORM 1 NOV 65 1473

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Welding Studies						
Boron-Aluminum Composites						
Gas-Tungsten Arc Fusion Welding						
Microstructural Observations						
Matrix Composition						

MICROSTRUCTURAL OBSERVATIONS OF
FUSION WELDED BORON-ALUMINUM COMPOSITES

by

J. Kennedy

Materials and Structural Mechanics

May 1972
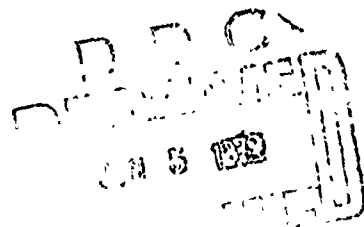
Approved by: *Charles E. Mack, Jr.*
Charles E. Mack, Jr.
Director of Research

ABSTRACT

Welding studies were conducted on boron-aluminum (B/Al) com-
posites to observe the effects of gas-tungsten arc fusion welding
on the boron reinforcing filaments and aluminum matrix. The objec-
tive of this investigation was to determine the basic potential of
fusion welding B/Al composites for possible structural applica-
tions. Microstructural observations after welding revealed matrix
fusion without apparent boron filament damage. Analysis of weld
metal regions indicated that aluminum filler metal additions inter-
mixed with the matrix and altered its chemical composition. It is
concluded that fusion welding of B/Al composites may be possible
by control of welding energy input.

TABLE OF CONTENTS

iii

INTRODUCTION

Exposure of boron filaments to molten aluminum raises the question of chemical reactivity and its effect on filament properties. Boron-aluminum interactions are time-temperature dependent and may be sluggish in the solid state, or very rapid in the presence of a superheated liquid aluminum matrix. Thermal treatments such as diffusion bonding, casting, and welding may induce various interfacial reactions detrimental to filament strength and composite structural efficiency. For example, it has been found that amorphous boron dissolves noticeably in molten aluminum at 1000°C (Ref. 1). In other work on cast boron-aluminum composites, several minutes of exposure to molten aluminum at about 740°C caused considerable interaction leading to partial dissolution and edge scalloping of the boron-filaments (Ref. 2). It was also determined (Ref. 2) that exposures up to three minutes at 740°C resulted in minimal observable reaction effects.

In a study of the interaction between boron and aluminum (Ref. 3), boron filaments were placed in molten aluminum at 680°C. After exposure times of 1 minute and 15 minutes, interaction layers were measured to be 2-3μm and 5μm, respectively. In a study of B/Al solid state reactions (Ref. 4), it was found that a time-temperature dependent incubation period exists after which a loss of strength occurs. In some cases, tensile strength increased during this period, suggesting some beneficial effects of the interfacial reaction. Studies of B/Al interactions during fusion welding have been generally quite limited. It is reported that gas-tungsten arc, electron beam, and plasma fusion welding usually result in severe weld embrittlement and filament degradation (Refs. 5,6). Typical effects on the boron included filament cracking, break-up, misorientation, and partial or complete dissolution. In the worst cases, reductions in composite strength at the weld joint have been as high as 90 percent. On the other hand, resistance spot welding of boron-aluminum, which also requires matrix fusion, has shown more promise in minimizing adverse thermal effects on the boron filaments (Refs. 5-8).

The most significant qualitative difference between resistance welding and the other fusion processes is the relatively lower thermal energy input of the former. The influence of welding energy input on interfacial reactions has also been demonstrated in welding studies on titanium-tungsten and titanium-graphite composites (Ref. 9). As welding energy input was increased, tungsten

1

dissolution became greater and titanium carbide formation around the graphite filaments grew thicker. It was concluded that thermal energy delivered to the composite during welding is a significant factor in controlling the nature of filament-matrix reaction products. High welding heats can increase dissolution between components, producing extensive diffusion zones and larger quantities of additional phases. Quantitative evaluation of these effects and their contributions to composite efficiency will be necessary for practical utilization in future applications.

It is clear that the specific effects of short time, high thermal energy exposure on boron-aluminum composites have not been completely characterized. This program was undertaken to obtain more insight on fusion welding of B/Al composites. The present work describes an initial study to observe and to assess qualitatively the condition of boron filaments and aluminum matrix after exposure to gas-tungsten arc welding.

EXPERIMENTAL PROCEDURE

Tests were conducted on 0.025-in. (50%-6 ply) and 0.050-in. (40%-9 ply) thick B/Al composite sheets, made from unidirectionally aligned 0.004-in.-diameter boron filaments and 6061 aluminum. The composites were fabricated by hot pressing. Fusion welding was performed using a standard 300 amp. ac/dc welding power supply with a manual gas-tungsten arc welding torch. An 0.040-in.-diameter thoriated tungsten electrode, alternating current, and argon gas shielding were employed during welding. All specimens were bead-on-sheet fusion welds; when filler metal was added during welding, 1/16-in.-diameter 4043 aluminum wire was employed.

Immediately prior to welding, the B/Al specimens were degreased by cloth wiping with isopropyl alcohol, followed by a light surface milling in the intended fusion region with a hand draw file. The specimens were clamped in a copper welding fixture with a 1/4-in. space between the hold-down bars. A copper back-up bar with a 1/4 in.-wide x 1/16-in.-deep groove was also used.

Specimens were metallographically prepared by minimizing final polishing time, first with diamond to $1\mu m$, and then with alumina to $0.05\mu m$. Boron filaments were also extracted for examination by leaching the aluminum matrix with dilute hydrochloric acid.

In addition to optical microscope observation of composite microstructures, scanning electron microscopy (SEM) was performed with a Cambridge Stereo-Scan instrument, and electron microprobe analysis was conducted with a Philips AMR-3 analyzer.

RESULTS AND DISCUSSION

The effect of increases in fusion welding energy input on 0.050-in.-thick B/Al composite was studied. The specimens used for this study were 1/4-in.-wide and 2-in.-long; they were clamped and welded from one side only under a stationary arc essentially producing a localized fusion spot weld. Under these conditions, the energy input (joules) is the product of arc power and fusion time (A x V x sec).

A transverse section of a weld made with 4043 Al wire addition at 6435 joules (26 A, 16.5 V, 15 sec) is shown in Fig. 1.
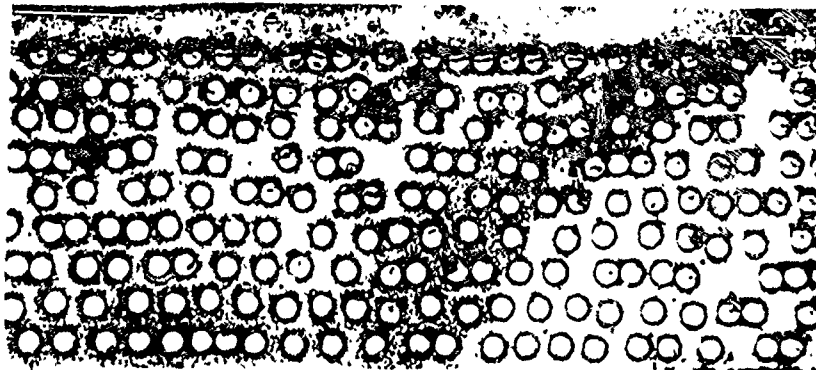
Fig. 1 Transverse Section of Fusion Weld in B/Al. Made with 4043 Filler wire at 6435 joules (30X)

Large pores were formed in the weld metal interior as contrasted to fine pores in the weld crown. Matrix melting has caused some shifting of the boron filaments in the fusion zone. A comparison of two welds made at 6435 joules with and without filler wire is shown in Fig. 2. These results generally typify the entire group of specimens made in this study that were welded up to energy levels of 18,000 joules. When filler wire was not added, the upper boron filaments were subjected to intense arc heating that caused severe filament fragmentation and dissolution. In addition, the difficulty in maintaining a stable weld puddle increased, usually resulting in the aluminum being drawn away from the puddle center to its edges, indicative of poor wetti. between boron and aluminum. On the other hand, these problems were largely eliminated
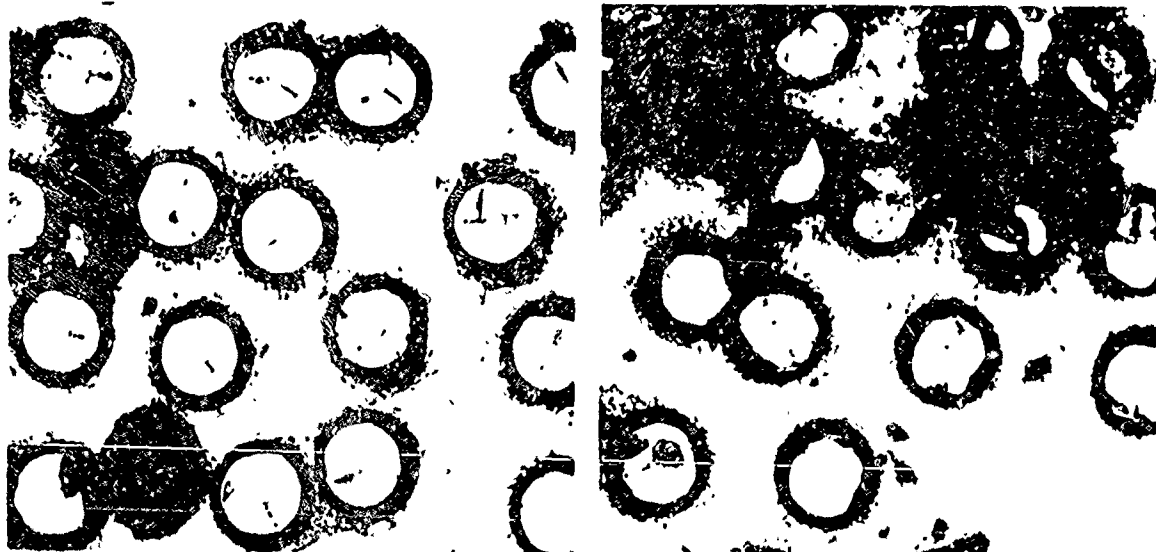
a) 4043 Wire Addition   b) No Wire Addition

Fig. 2 Comparison of Fusion Welds Made at 6435 Joules (150X)

when filler wire was present. Apparently, the additional Si-
enriched filler metal helps to shield the top layers of boron and
promotes metal flow into the matrix, as evidenced by the penetra-
tion observed in Fig. 1. Due to the limited scope of this initial
work, a full spectrum of fusion effects have not been determined.
This includes the effects of higher energy inputs, the welding of
thicker sheet, and the effect of longer fusion passes. However,
it is known qualitatively that excessive energy inputs will cause
significant filament damage and displacement regardless of filler
metal additions.

It should be noted that a certain percentage of filament
damage, such as radial cracking and contact fragmentation, as
shown in Figs. 2 and 4, is considered "normal" and also exists to
varying degrees in as-received and welded B/Al composite sheet.
This damage is believed to occur during primary fabrication of the
composite.

An analysis was made of the microstructure from a fusion welded bead-on-sheet specimen of 0.025-in.-thick B/Al, shown schematically in Fig. 3. This specimen was welded from both sides (not simultaneously) using 4043 wire addition, at an energy level of about 4950 joules/in. (20 A, 16.5 V, 4 in./min). A weld region was randomly selected from this specimen for subsequent examination by various techniques, as shown in Fig. 4. Our interest was to observe particular effects on the boron and the matrix resulting from this exposure. In Figs. 3 and 4, the SEM region shows the filaments intact within an apparently sound matrix.

The distinct grain boundaries in the matrix are clearly evident in the light microscopy photograph of Fig. 4. The presence of Si in this region is confirmed by the microprobe analysis that shows a definite correlation between the grain boundaries and Si-rich regions. It can also be noted that the Si distribution is relatively uniform through the specimen thickness. The average Si concentration after welding was calculated to be about 4.7 percent; the Si concentration is unwelded as-received composites was 0.58 percent. The nominal Si distribution in 4043 wire is 5 percent and in 6061 about 0.5 percent. The matrix appears to have been completely melted and fairly uniformly enriched with filler metal while the filaments remained apparently undamaged. This microstructure appears to be typical of a Si-rich condition in aluminum welds and castings (Refs. 10,11) where relative insolubility of Si in Al causes dispersion of small areas of Al-Si eutectic in the Al matrix and grain boundary enrichment. A Si layer or ring is also seen immediately adjacent to each filament (in some cases, a double Si ring is apparent). It is likely that as freezing progressed in the matrix, a solidification front rich in Si advanced to the filament periphery where the Si then segregated as along a grain boundary.

After being polished and etched, the boron usually stands slightly in relief above the matrix, making sharp planar focusing of both B and Al difficult with the optical microscope; this results in the characteristic shadowing around each filament.

Examination of the B/Al interfacial region at higher SEM magnifications revealed a portion of the interface configuration to be in the form of a small concave fillet between the filament and matrix, as shown in Fig. 5. A somewhat rough or jagged texture was also discernible in the transition zone vicinity of various filaments.
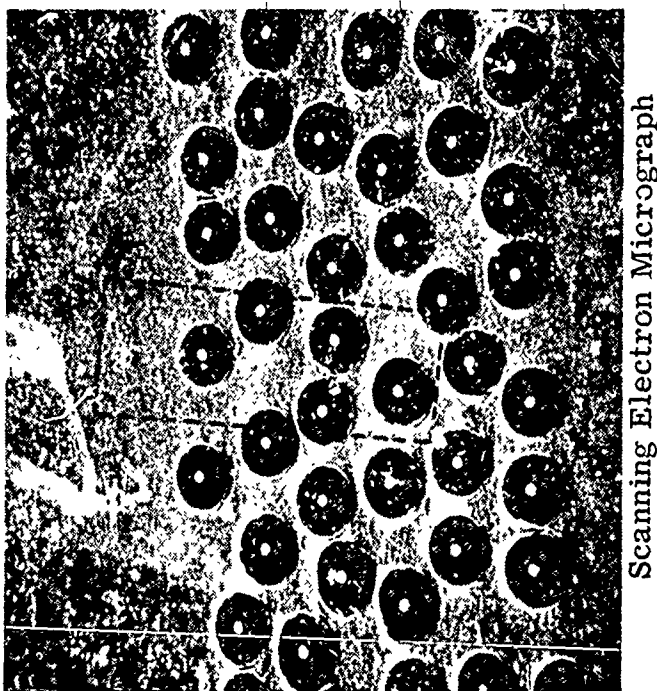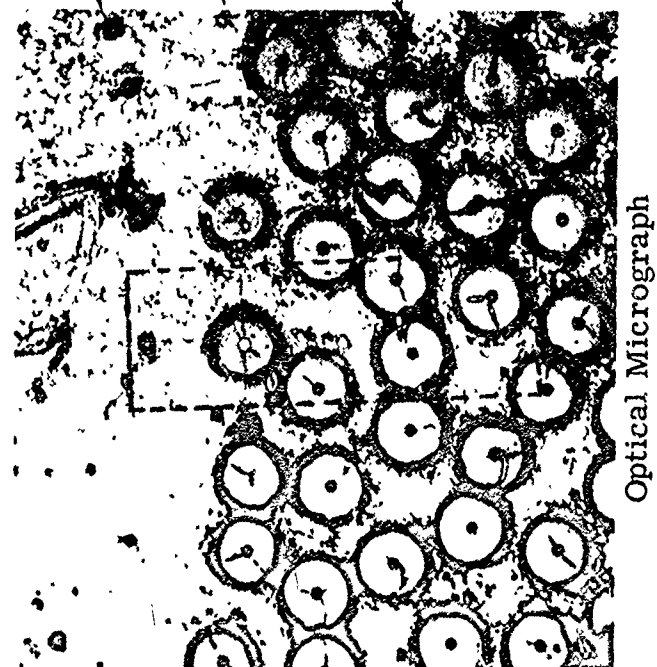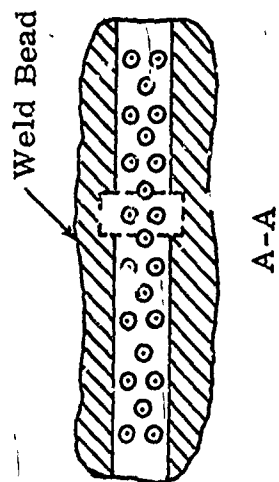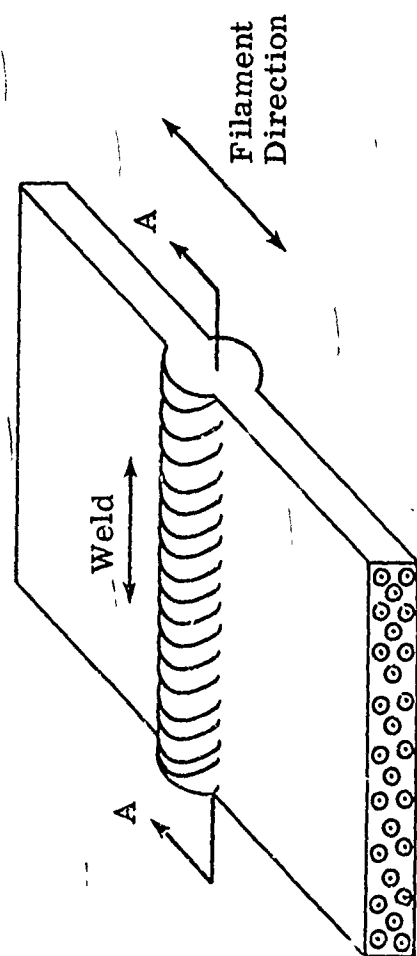
Weld Bead

A-A

Filament Direction

A

Weld

A

Scanning Electron Micrograph

Weld Bead

Original Boundary of Composite

B/AL Composite

100x Magn

Optical Micrograph

Fig. 3 B/AL Weld Region Selected For Examination

7
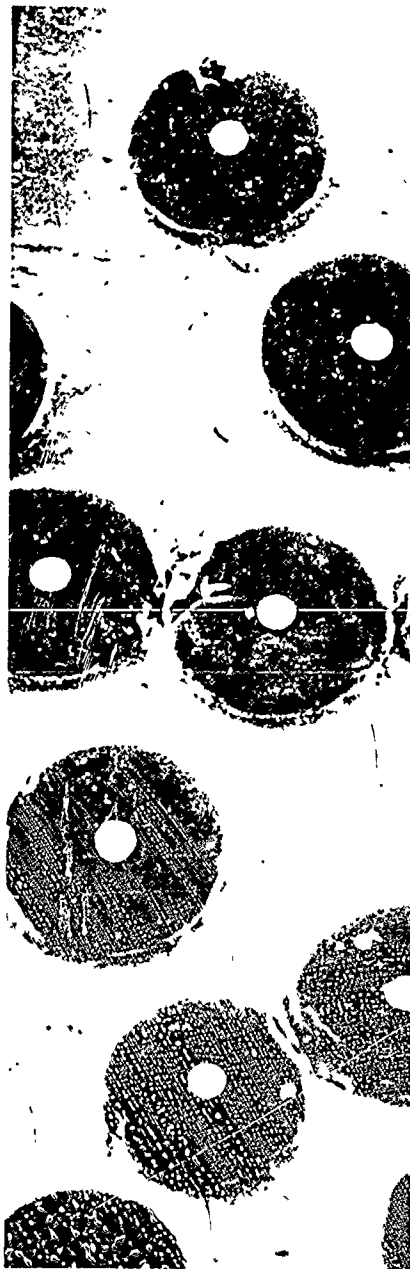
Silicon Distribu-
tion Electron
Microprobe (400X)

Scanning Electron
Micrograph (500X)

Light Micrograph (500X)

Fig. 4 Comparison of Selected Region in Fusion Welded B/Al
Composite (Reduced 35% on Reproduction)

Fig. 5 B/Al Interface in Weld Region

Further SEM observation of B/Al interactions was made on
welded specimens in which the matrix was leached to expose boron
filaments. Figure 6 is a comparison between as-received and as-
welded B/Al composite. In the welded specimen, to which 4043
Al wire was added, the variable mottled surface texture of the
boron filaments is evident. The filigreed matrix between the fila-
ments, resulting from a differential etching rate, probably repre-
sents a skeletal grain boundary network, enriched in Si as a
result of fusion welding. Subsequent electron microprobe analysis
showed these areas to be Si-rich relative to the as-received
composite. Microprobe scans over the filaments in the welded
specimen also showed significant concentrations of Al and Si.
The work by Klein (Ref. 4) on solid state reactions in B/Al com-
posites showed that the interaction phase has an uneven, acircular
appearance with needlelike protrusions into the matrix. The inter-
action product in that work has been tentatively identified as
AlB_2. The reaction product in the welded condition has not yet
been identified, but the presence of a combination of complex in-
termetallic compounds is not unlikely.
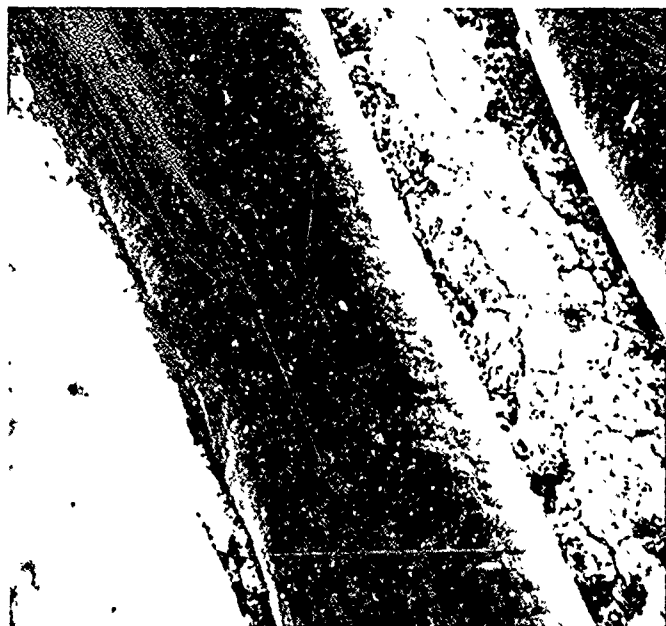
As Received   (400X)
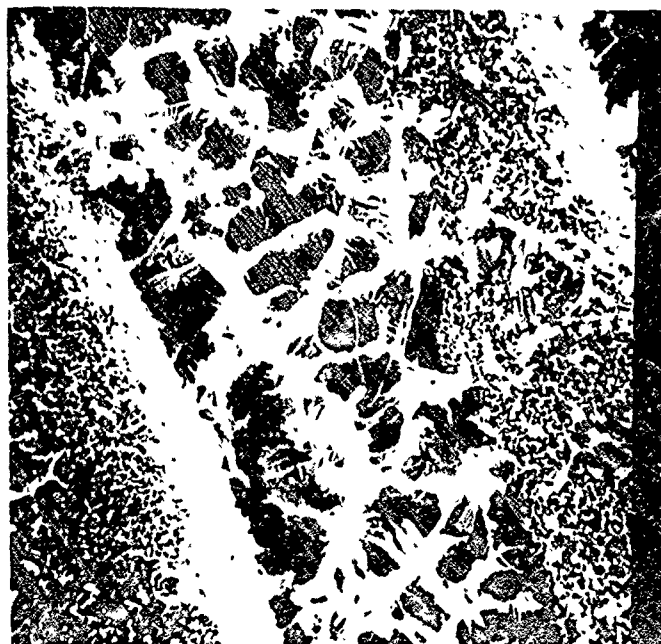
Welded   (400X)

Fig. 6   Scanning Electron Micrographs of Exposed
Boron Filaments

CONCLUSIONS

It has been shown that thin-sheet B/Al composites can be subjected to certain fusion welding thermal conditions without severely damaging the boron filaments. It is possible to add and to intermix filler wire through the matrix to alter its chemical composition significantly. These results indicate that fusion welding of B/Al may be possible by control of welding energy input. Identification of the subsequent fusion reaction products, and the effects of those products on composite mechanical properties, has not yet been determined but is planned in continuing studies. In addition, knowledge of reaction growth rate kinetics and the means to control the reaction products during welding would increase the potential of B/Al for consideration as welded structures.

REFERENCES

1. Hansen, M., *Constitution of Binary Alloys*, McGraw-Hill Book Co., New York, 1958.

2. Hill, R. et al., "The Development and Properties of Cast Boron/ Aluminum Composites," *Advances in Structural Composites*, 12th SAMPE Symposium, Vol. 12, p. AC-18, Western Periodicals Co., N. Hollywood, California, October 1967.

3. Restall, J. et al., *Metals and Materials*, November 1970, pp. 467-473.

4. Klein, M. and Metcalfe, A., *Effect of Interfaces in Metal Matrix Composites on Mechanical Properties*, AFML-TR-71-189, Solar Division of International Harvester Company, San Diego, California, October 1971.

5. Schaefer, W. and Christian, J., *Evaluation of the Structural Behavior of Filament Reinforced Metal-Matrix Composites*, Convair Division of General Dynamics, San Diego, California, AFML-TR-64-36 (Vols. I, II, III), January 1969.

6. *Structural Design Guide for Advanced Composite Applications: Vol. 3 - Manufacturing*, 2nd Ed., pp. 8.4.2-8.4.18, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio, January 1971.

7. Hersh, M., *Welding Journal*, Vol. 47, No. 9, pp. 404-409s, 1968.

8. *Development of Improved Metal-Matrix Fabrication Techniques for Aircraft Structure*, Report No. GDC-DBG70-002-1, Convair Division of General Dynamics, San Diego, California, July 1970.

9. Kennedy, J. and Geschwind, G., to be presented at the 2nd International Conference on Titanium, Boston, Massachusetts, May 1972.

10. Knight, J., *Welding Kaiser Aluminum*, Oakland California, 1967.

11. Brick, R. and Phillips, A., *Structure and Properties of Alloys*, 2nd Ed., McGraw-Hill Book Co., New York, 1949.